REMARKS

Claims 20-22, 24 and 27-60 are pending in this application. By this Amendment, claims 20, 21, 37-39 and 43-49 are amended. Claims 43-45 are amended merely for consistency of format. Support for the amendments to claims 20, 21, 37-39 and 46-49 can be found throughout the specification as originally filed, for example, on page 25, line 3. Thus, no new matter is added by these amendments.

Also by this Amendment, new claims 50-60 are added. Support for new claims 50-56 can be found in the specification and claims as filed, for example, at page 28, lines 12-21. Support for new claims 57-60 can be found in the specification as filed, for example, at page 24, last line through page 27, line 12 and at page 28, lines 12-21. Thus, no new matter is added by these new claims.

The courtesies extended to Applicant's representatives by Examiner Norton, Examiner Anderson and Examiner Kunemund at the interview held December 16, 2003, are appreciated. The reasons presented at the interview as warranting favorable action are incorporated into the remarks below and constitute Applicants' record of the interview. Applicants have also amended the claims as discussed in the interview. Further, in view of the Examiners' request for declaration evidence from an independent source rather than from an inventor, Applicants attach a Declaration from one of the pre-eminent experts in the field, Dr. Lionel C. Kimerling, Thomas Lord Professor of Materials Science and Engineering, Director of the Materials Processing Center, Director of the Microphotonics Center, and Leader of the Electronic Materials Research Group at the Massachusetts Institute of Technology (MIT).

Claims 20-22, 24, 27-29 and 32-49 are rejected under 35 U.S.C. §103(a) as allegedly unpatentable over J. Minahan et al., Irradiated Solar Cells Fabricated From Gallium-Doped/Boron-Doped FZ and CZ Silicon (Conf. Rec. IEEE Photovoltaic Spec. Conf. (1982)

16th, 310-315), in view of Wolf et al., Silicon Processing for the VLSI Era, Vol. 1: Processing Technology (Lattice Press, Sunset Beach, CA, USA pp. 1-35, 1986). The Office Action also rejects claims 30 and 31 under 35 U.S.C. §103(a) as allegedly unpatentable over Minahan in view of Wolf, as applied to claims 20-22, 24, 27-29 and 32-49, and further in view of U.S. Patent 6,147,297 to Wettling et al. Applicants respectfully traverse these rejections.

Applicants respectfully submit that one of ordinary skill in the art would not have been motivated by the disclosures of Minahan, Wolf and Wettling to produce a solar-cell-grade, quartz-crucible Czochralski silicon single crystal or wafer having a diameter of at least four inches, with gallium as the dopant that controls the resistivity of the crystal, the amount of gallium providing the recited concentration and/or resistivity. Nor would such a person have had any reasonable expectation that such a product could successfully be made with the unexpected beneficial properties that Applicants have demonstrated.

I. Background of the Invention

Fifty years after the invention of semiconductor solar cells at Bell Laboratories, commercial solar cells are made from silicon single crystals containing boron as the dopant that controls resistivity of the crystals, and still reach an efficiency of only 16-17%, in sizes ranging from 100-150 cm^2. See Fraunhofer ISE PV Charts: Assessment of PV Device Performance, 11th ed. (1998) (providing statistics relating size and efficiency in silicon single crystal solar cells, and showing that none of the cells with an area of 100 cm^2 or above had a conversion efficiency, $\eta \pm U_{95}$, greater than 17.5%) ("Fraunhofer ISE PV Charts") (attached). Because silicon single crystal solar cells can only utilize light in the wavelength range of about 0.35-1.1 μm, silicon single crystal solar cells have a theoretical efficiency of only about 28%, as discussed during the July 1 and December 16 interviews. The conversion efficiency of solar cells using quartz-crucible Czochralski silicon single crystals was generally low, in

particular due to photo-degradation caused by oxygen and boron in the crystal. See Specification, page 23, lines 3-12.

As explained by Dr. Abe during the July 1 interview, Applicants decided to look for a way to dramatically increase the use of solar cells in order to preserve natural resources and the environment and facilitate energy independence. The greatest barrier to the use of solar cells for the generation of power is cost, and the greatest problem currently facing researchers is how to lower the costs of solar energy, by lowering the production costs of solar cells and/or by increasing the conversion efficiency of the solar cells. As discussed during the July 1 interview, a large-area solar cell that is not subject to loss of conversion efficiency due to photo-degradation had not been produced and was considered a great challenge in the field of solar cell research. See Specification, page 2, lines 8-21; page 4, lines 2-4; Table 1 (the results of Comparative Example 4 disclose a 10 cm x 10 cm boron-doped Czochralski silicon single crystal having conversion efficiencies of 19.8 before and 17.9 after photo-degradation, respectively, in spite of having a lower oxygen content than the gallium-doped Czochralski silicon single crystals of Example 1). The solution Applicants chose to pursue was to increase the efficiency, the area (thus increasing the productivity and lowering the cost) and the lifetime of solar cells while using the low-cost, quartz-crucible Czochralski process, in spite of the understanding in the art that increasing the area decreases the efficiency and lifetime of such solar cells, and that the quartz-crucible Czochralski process is less desirable even for small-diameter solar cell production. See Fraunhofer ISE PV Charts ("Large area solar cells tend to show lower conversion efficiencies than smaller area cells of corresponding technology"); Abe Declaration of Record, submitted June 4, 2003, paragraph 7; Kimerling Declaration (attached), paragraphs 6, 8-14 and 20-22; Minahan. Applicants surprisingly succeeded in their approach. See S. W. Glunz et al., 100 cm^2 Solar Cells on Czochralski Silicon with an Efficiency of 20·2%, *Prog. Photovolt. Res. Appl.* 2000, Vol. 8, pp. 237-240,

238 (of record) ("To our knowledge, this is the first time that an efficiency of more than 20% was achieved for a cell of 100 cm^2 on Cz-silicon").

II. The Claimed Invention

Applicants have produced, for the first time, silicon single crystals for solar cells, formed by the relatively low-cost Czochralski method using a quartz crucible, and therefore containing a large amount of oxygen, with a large area coupled with increased efficiency and lifetime. In particular, Applicants have unexpectedly found that a highly efficient, low-cost, long-lifetime silicon single crystal for a solar cell can be achieved by the combination of:

1. producing the crystal according to the Czochralski method using a melt in contact with a quartz crucible;

2. adding gallium as a dopant that controls resistivity of the crystal;

3. using the gallium in an amount that produces a resistivity of 0.1 to 5 $\Omega \cdot cm$ (claims 20, 22, 24, 27-42, 46 and 48), or a gallium concentration of 5×10^{17} atoms/cm^3 to 3×10^{15} atoms/cm^3 (claims 21, 44, 47 and 49);

4. forming the single crystal with a diameter of four inches or more; and

5. using the single crystal for a solar cell.

The combination of all of these limitations is important in the claimed invention. The claimed combination, unlike anything known or suggested by the prior art, achieves a major increase in light conversion efficiency without significant photo-degradation, in easily grown, large-diameter crystals with high crystal strength. This invention moves solar energy farther than ever before into the realm of commercially practical alternative energy sources, and has been internationally acclaimed as a result.

As discussed in the December 16 interview, the significance of the claimed combination and the unexpected superiority of the results thereof are documented in

substantial objective evidence. In addition to objective data in the specification and two Rule 132 Declarations of Dr. Abe, this documentation includes:

1. the Fraunhofer ISE PV Charts (copy attached);

2. the Rule 132 Declaration of an eminent independent expert in the field, Professor Lionel C. Kimerling, (Kimerling Declaration) (copy attached);

3. S. W. Glunz et al., 100 cm^2 Solar Cells on Czochralski Silicon with an Efficiency of 20·2%, *Prog. Photovolt. Res. Appl.* 2000, Vol. 8, pp. 237-240, 238 (of record);[1]

4. S.W. Glunz et al., Comparison of Boron- and Gallium-doped p-Type Czochralski Silicon for Photovoltic Application, *Prog. Photovolt. Res. Appl.* 1999, Vol. 7, pp. 463-469 (of record);[2]

5. Kunihiro Kawamoto et al., A High-Efficiency HIT™ Solar Cell (21.0% ~100 cm^2) with Excellent Interface Properties, *Technical Dig. of the Int'l PVSEC-12*, 2001, pp. 289-290 (copy attached);

6. T. Saitoh et al., Light Degradation and Control of Low-Resistivity CZ-Si Solar Cells, *Technical Dig. of the Int'l PVSEC-11*, 1999, pp. 553-556 (of record); and

7. Special Paper Award, 11th International Photovoltaic Science and Engineering Conference (of record).

III. Rejections Under 35 U.S.C. §103(a)

Section 103 requires a consideration of the claimed invention as a whole and the prior art as a whole in making an obviousness determination. This involves considering the scope and content of the prior art, the differences between the prior art and the claims at issue, the level of ordinary skill in the art, and any secondary considerations that may be present.

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[1] See Abe Declaration submitted herewith, paragraph 6, regarding the independent nature of this document in spite of the fact that Dr. Abe is listed on it as an author.

[2] See footnote 1, *supra*.

Graham v. John Deere, 383 U.S. 1, 17, 148 USPQ 459, 467 (1966). Combination of references to support a rejection requires a motivation or suggestion in the art that one should carry out the claimed invention, and would have a reasonable expectation of success in doing so. In re Vaeck, 947 F.2d 488, 493, 20 USPQ2d 1438, 1442 (Fed. Cir. 1991). Evidence of secondary considerations such as unexpected results, including such evidence in the specification, must be taken into account. MPEP §2144.08 II. A.

A. Scope and Content of the Prior Art

1. Minahan

Minahan was cited as disclosing a solar-cell-grade gallium-doped Czochralski silicon single crystal with resistivity overlapping the resistivity ranges set forth in claims 20, 37, 43-46 and 48. Minahan is directed to comparing the tolerance to electron beam fluence levels of boron- and gallium-doped Floating Zone and Czochralski solar cells. See Minahan, Abstract. Minahan compares the tolerance to electron beam radiation, a space-use consideration for solar cells that is not related to photo-degradation effects (Kimerling Declaration, paragraph 18), of two-inch diameter sections of boron- and gallium-doped silicon single crystals grown by the Czochralski and Floating Zone methods and even smaller-diameter (0.3-0.8 inch) gallium-doped crystals grown by the cold crucible method. See Minahan, Abstract; page 311, col. 1, first full paragraph; fourth full paragraph.

Minahan notes gallium-dopant-induced resistivities of "~ 0.1 Ω·cm and ~ 10 Ω·cm" for gallium-doped Czochralski silicon. See Minahan, page 310, col. 2, third full paragraph. The upper value is twice as high as the upper end of the claimed range, and Minahan suggests, by its lack of differentiation among the resistivities considered, that this upper value, 10 Ω·cm, is sufficiently low for solar cell purposes. See Minahan, Tables 3(a)-3(c) (showing similar data for 2 Ω·cm boron-doped Czochralski crystals and 10 Ω·cm gallium-

doped Czochralski crystals). In addition, the actual value that Minahan uses for "~ 0.1 Ω·cm" is 0.07 Ω·cm (see Minahan, Table 2). The resistivity of Minahan's Czochralski crystals thus is 0.07 and 10 Ω·cm, not 0.1-10 Ω·cm. Minahan provides no solar cell data for gallium-doped, quartz-crucible Czochralski crystals having a resistivity other than 10 Ω·cm.

Minahan notes that problems arise in quartz-crucible Czochralski crystals, at least in part because of high oxygen content. Minahan discusses Floating Zone (FZ) , cold crucible, and quartz-crucible Czochralski (CZ) methods for forming solar-cell silicon single crystals in terms of electron beam radiation tolerance. At page 310, first column, second paragraph, Minahan teaches that the Floating Zone method provides better radiation tolerance than the Czochralski method, associated with the lower oxygen content of Floating Zone crystals. "Measurements of irradiation effects on FZ and CZ silicon imply superior radiation tolerance for the FZ silicon and this has been associated with the much lower concentration of oxygen in FZ relative to the oxygen content found in CZ grown silicon." The same point is repeated at the second paragraph of column 1 of page 311 ("FZ superiority to CZ silicon in this regard has been associated with reduced levels of oxygen ... CZ silicon, because it is grown from a melt contained within a quartz crucible, contains very high quantities of oxygen and other impurities that might be dissolved from the quartz during contact with the silicon melt. The CZ is therefore a contaminating process."). Minahan teaches that the cold crucible and Floating Zone methods are less contaminating than the Czochralski method, and crystals formed by the cold crucible and Floating Zone methods include less oxygen impurities than quartz-crucible Czochralski crystals. See Minahan, page 311, col. 2, second full paragraph; page 312, col. 1, final full paragraph. Minahan's final conclusion at the last paragraph of text on page 312 is that cold crucible crystals provide even better oxygen levels than Floating Zone crystals.

The cold crucible method taught by Minahan involves pulling a silicon single crystal from a melt supported by solid silicon below and an rf field around the sides. See Minahan, page 311, col. 1, third paragraph. Because the melt is not contained by a crucible but rather by an rf field and thus contacts only its own solid phase, cold crucible crystals, like Floating Zone crystals, have reduced impurities compared to quartz-crucible Czochralski crystals. See Minahan, page 311, col. 1, third and fourth paragraphs. However, the size of cold crucible silicon single crystals appears to be limited by physical constraints to small diameters. See Minahan, page 311, col. 1, fourth paragraph (disclosing cold crucible diameters of 0.3-0.8 inches). The size of Floating Zone crystals is also limited. See Minahan, page 311, col. 1, first paragraph and Wolf, page 21, third paragraph ("it appears that the maximum FZ size is ~100mm because of stability problems of the molten zone under gravity conditions"). Thus these processes have not been used commercially. Minahan further teaches that, because the oxygen concentration of Floating Zone crystals is lower than that of Czochralski crystals, the radiation tolerance of Floating Zone crystals relative to Czochralski crystals is improved. See Minahan, page 311, col. 1, second paragraph. Also, the Floating Zone method and cold crucible method are higher cost methods than the Czochralski process. See Minahan, page 310, col. 1, third paragraph; Wolf, page 21, third paragraph; and Specification, page 5.

In addition, Minahan teaches using polished wafers made from silicon single crystals for solar cells. See Minahan, page 311, col. 1, fifth full paragraph.

2. <u>Wolf</u>

Wolf teaches generally the subjects of silicon single crystal growth and wafer preparation by the Czochralski and Floating Zone methods, and was cited to show that it was known to prepare large-diameter silicon single crystals.

Wolf teaches methods that can be used for preparing electronics-grade silicon, not solar-cell-grade silicon single crystals, having diameters of up to approximately eight inches.

See Wolf, page 1, first full paragraph; page 6, first full paragraph ("Single crystal silicon is grown from melts of electronic grade polycrystalline silicon (EGS)" - emphasis in original); page 8, third full paragraph; Fig. 7. Wolf does not describe these sizes as conventional for Czochralski silicon single crystals of solar cell grade.

Wolf also teaches that, generally, Czochralski silicon single crystals are grown from a melt in a fused silica crucible. See Wolf, page 9, first paragraph. Wolf notes that, because of dissolution of the crucible during crystal growth, oxygen is included in Czochralski silicon single crystals, in concentrations that can be between 5×10^{17} atoms/cm^3 to 3×10^{15} atoms/cm^3. See Wolf, page 16, second paragraph. Wolf further teaches that control of the oxygen content is very difficult at best. See Wolf, page 16, second paragraph ("The number of variables and their potential interactions with one another make it difficult to develop models which accurately predict oxygen incorporation in CZ crystals"). Wolf thus teaches that Czochralski crystals are inherently less pure than Floating Zone crystals, which are produced by establishing, using an rf field in an inert atmosphere or vacuum, a molten zone in a polysilicon rod, which is contacted with a seed crystal and pulled to allow crystal formation. See Wolf, page 22, first and second paragraphs. Wolf also teaches that the Floating Zone method is incapable of producing crystals in large diameters or at low cost, because "it appears that the maximum FZ size is ~100mm because of stability problems of the molten zone under gravity conditions." See Wolf, page 21, third paragraph.

Wolf notes that problems arise in quartz-crucible Czochralski crystals, at least in part because of high oxygen content. See Wolf, page 11, third paragraph; page 30, first full paragraph. Wolf teaches that Floating Zone crystals have a higher purity and lower and more predictable oxygen contamination than Czochralski crystals. See Wolf, page 6, first full sentence; page 16, second full paragraph; page 17, first full paragraph; page 21, second and third paragraphs. Wolf teaches that devices calling for high-purity starting material are

typically fabricated from Floating Zone silicon (page 6, second full sentence), and that "in the foreseeable future, CZ and FZ methods are likely to continue serving their respective application areas" (page 22, fourth full sentence).

3. Wettling

Wettling is cited for its teachings of high-efficiency solar cells. Wettling teaches solar cells having high conversion efficiencies attributable to the grid-emitter structure and the doping of surface layers on a substrate in the formation of the solar cell. See Wettling, col. 2, lines 26-40; col. 4, lines 11-14. Wettling teaches that high-efficiency solar cells can be formed by using surface doping with a grid emitter structure or a PERL structure. See Wettling, col. 1, lines 38-54. Wettling provides no hint that high conversion efficiency can be achieved by way of the present invention.

Wettling is silent as to the identity and concentration of dopants, as well as the range of resistivities produced by its surface doping of the base substrate. Wettling does not teach the use of gallium-doped silicon single crystals in the formation of these high-efficiency solar cells. Indeed, Wettling does not contain any reference to silicon single crystals, or to Czochralski silicon single crystals doped with gallium as the dopant to control resistivity. Instead, the only material disclosed as the base material is silicon dioxide. See Wettling, Fig. 1; col. 1, lines 38-54; but see A. Wang et al., 24% Efficient Solar Cells, Appl. Phys. Lett. **57** (6) 602 (1990) (copy attached) (float zone wafers used as substrate).

Wettling teaches doping the surface of a silicon dioxide substrate with an n^{++} type dopant and then further doping with an n^{+} type dopant or pre-doping the surface of a substrate, by a process such as diffusion doping, with a p^{+} type dopant and then doping the surface with an n^{++} type dopant. See Wettling, col. 4, lines 11-14; col. 6, lines 38-48. However, Wettling offers no distinction among dopants of any particular type.

B. Differences Between The Prior Art and The Claims

The claimed invention achieves a highly efficient, low-cost, long-lifetime silicon single crystal for a solar cell with a large area by the combination of producing the crystal according to the Czochralski method using a melt in contact with a quartz crucible, adding gallium as a dopant that controls resistivity of the crystal, using the gallium in an amount that produces a resistivity of 0.1 to 5 $\Omega\cdot$cm (claims 20, 22, 24, 27-42, 46 and 48), or a gallium concentration of 5×10^{17} atoms/cm^3 to 3×10^{15} atoms/cm^3 (claims 21, 44, 47 and 49), forming the single crystal with a diameter of four inches or more, and using the single crystal for a solar cell. As discussed in detail below, none of the cited references, alone or in combination, teach or suggest this combination, or the beneficial results that proceed from this combination.

1. Minahan

Minahan does not teach the combination of producing the crystal according to the Czochralski method using a melt in contact with a quartz crucible, adding gallium as a dopant that controls resistivity of the crystal, using the gallium in an amount that produces a resistivity of 0.1 to 5 $\Omega\cdot$cm (claims 20, 22, 24, 27-42, 46 and 48), or a gallium concentration of 5×10^{17} atoms/cm^3 to 3×10^{15} atoms/cm^3 (claims 21, 44, 47 and 49), forming the single crystal with a diameter of four inches or more, and using the single crystal for a solar cell. Specifically, Minahan does not teach the claimed resistivity range, the claimed concentration ranges of gallium dopant, or the claimed crystal diameter. See Minahan, page 310, col. 1, second paragraph. Nor does Minahan teach or suggest the beneficial effects of the claimed invention.

Minahan teaches both gallium and boron as dopants for solar-cell-grade silicon single crystals. See Minahan, Abstract. In contrast, Applicants found that by controlling the

resistivity of a quartz-crucible Czochralski silicon single crystal with gallium in the claimed ranges, solar cells having a large area and capable of having high conversion efficiencies can be obtained. See Abe Declaration of Record, submitted June 4, 2003, paragraph 6; Specification, pages 4-8.

Minahan does not teach using gallium in an amount that produces a resistivity of 0.1 to 5 Ω·cm, or a gallium concentration of 5×10^{17} atoms/cm^3 to 3×10^{15} atoms/cm^3. Rather, Minahan teaches two values, 0.07 and 10 Ω·cm, as the resistivities for gallium-doped Czochralski silicon single crystals. See Minahan, Table 2. Minahan fails to teach or suggest the importance of the claimed range or the unexpected peak in conversion efficiency without substantial photo-degradation that occurs in this range, as demonstrated in Figure 4 and Table 1 of the specification. To the contrary, Minahan provides no solar cell data for gallium-doped, quartz-crucible Czochralski crystals having a resistivity other than 10 Ω·cm.

Contrary to the assertion of the Office Action, Minahan does not succeed in "disclosing a gallium doped single crystal, suitable for use in solar cells, produced according to the Czochralski method with resistivity overlapping that claimed by the applicants." Office Action, page 3. Rather, Minahan discloses gallium-doped silicon single crystals of 0.07 and 10 Ω·cm, both of which are outside of the specific range claimed by Applicants, and which do not produce the superior conversion efficiencies that occur with the claimed invention without substantial photo-degradation, as clearly shown by Figure 4 (conversion efficiency at 0.07 Ω·cm below 17%, and conversion efficiency at 10 Ω·cm even lower) and Table 1.

In addition, Minahan does not disclose specific gallium concentrations. Minahan fails to recognize the narrow range of gallium concentrations and gallium-induced resistivities that provide the unexpected peak of conversion efficiency without substantial photo-degradation, which Applicants discovered for the first time, for gallium-doped, quartz-crucible

Czochralski silicon single crystals having a diameter of four inches or more and gallium concentrations or gallium-controlled resistivities in the claimed ranges. Rather, Minahan teaches improving electron beam radiation tolerance, a phenomenon that is unrelated to photo-degradation effects, such as loss of conversion efficiency. See Kimerling Declaration, paragraph 18.

Minahan teaches that, in order to improve electron beam radiation tolerance, gallium is used as a dopant and either the Floating Zone or cold crucible method is used to lower oxygen concentration. See Minahan, page 312, col. 1, third full paragraph, sixth full paragraph. However, the claimed invention requires silicon single crystals grown by the oxygen-content-increasing quartz-crucible Czochralski method, not the Floating Zone or cold crucible methods. Indeed, this aspect of the claimed invention significantly improves the properties of the product, contrary to the teachings of Minahan. See Kimerling Declaration, paragraphs 6, 13, 17, 20 and 21.

In addition, Minahan teaches small silicon single crystals, approximately two inches in diameter for Floating Zone crystals and less for cold crucible crystals, rather than the diameter of four inches or more required by the claims. Because of the constraints of gravity, the diameters of both Floating Zone and cold crucible silicon single crystals are limited. See Minahan, page 311, col. 1, first paragraph, fourth paragraph; Wolf, page 21, third paragraph. However, quartz-crucible Czochralski crystals are not so limited, and can achieve much larger crystal diameters, but with higher and less predictable oxygen concentrations. See Wolf, pages 6-7, Fig. 7. The claimed invention unexpectedly capitalizes on these oxygen concentrations, without the negative effects of Minahan and Wolf. See Kimerling Declaration, paragraph 13.

Thus, Minahan fails to disclose several elements of the claimed combination.

2. Wolf

Wolf does not teach the combination of producing the crystal according to the Czochralski method using a quartz crucible, adding gallium as a dopant that controls resistivity of the crystal, using the gallium in an amount that produces a resistivity of 0.1 to 5 $\Omega\cdot$cm (claims 20, 22, 24, 27-42, 46 and 48), or a gallium concentration of 5×10^{17} atoms/cm^3 to 3×10^{15} atoms/cm^3 (claims 21, 44, 47 and 49), forming the single crystal with a diameter of four inches or more, and using the single crystal for a solar cell. Specifically, Wolf does not teach producing a solar-cell-grade silicon single crystal according to the Czochralski method using a melt in contact with a quartz crucible, adding gallium as the dopant to control resistivity, the claimed resistivity or concentration ranges of gallium dopant, or producing a solar-cell-grade single crystal with a diameter of four inches or more.

Wolf, in contrast to the claimed invention, discloses electronics-grade silicon single crystals, and makes no reference to solar-cell-grade silicon single crystals formed by any method. In addition, Wolf makes no reference to gallium doping or to gallium-dopant concentration. Wolf fails to teach or suggest the specific resistivity range or concentration of gallium dopant in quartz-crucible Czochralski crystals, or the unexpected peak in conversion efficiency without substantial photo-degradation that occurs in this range.

Further, Wolf does not even suggest the peak of conversion efficiency, which Applicants discovered for the first time, for gallium-doped, quartz-crucible Czochralski silicon single crystals having gallium concentrations or gallium-controlled resistivity in the claimed ranges. Nor does Wolf provide any suggestion to produce a solar-cell-grade silicon single crystal with a diameter of four inches or more.

Thus, Wolf also fails to disclose several elements of the claimed combination.

3. Wettling

Wettling does not teach the combination of producing the crystal according to the Czochralski method using a melt in contact with a quartz crucible, adding gallium as a dopant that controls resistivity of the crystal, using the gallium in an amount that produces a resistivity of 0.1 to 5 $\Omega \cdot$cm (claims 20, 22, 24, 27-42, 46 and 48), or a gallium concentration of 5 x 10^{17} atoms/cm^3 to 3 x 10^{15} atoms/cm^3 (claims 21, 44, 47 and 49), forming the single crystal with a diameter of four inches or more, and using the single crystal for a solar cell. Specifically, Wettling does not teach producing a solar-cell-grade silicon single crystal according to the Czochralski method using a melt in contact with a quartz crucible, adding gallium as the dopant to control resistivity, the claimed resistivity and concentration ranges of gallium dopant, or the claimed crystal diameter.

Wettling teaches high-efficiency solar cells, but does not disclose producing these solar cells from silicon single crystals formed by the quartz-crucible Czochralski method. Wettling does not teach the use of gallium-doped silicon single crystals in the formation of these high-efficiency solar cells. Indeed, Wettling does not contain any reference to silicon single crystals, much less quartz-crucible Czochralski crystals doped with gallium as the dopant to control resistivity. Instead, the only material disclosed as the base material is silicon dioxide. See Wettling, Fig. 1; col. 1, lines 38-54; but see A. Wang et al., 24% Efficient Solar Cells, *Appl. Phys. Lett.* **57** (6) 602 (1990) (float zone wafers used as substrate).

Further, Wettling does not teach or suggest using gallium as the dopant in a single crystal to control resistivity, or the claimed range of resistivities controlled by a gallium dopant or the claimed concentrations of gallium dopant. Wettling further does not teach or suggest that a peak in conversion efficiency without substantial photo-degradation could or should be expected with these resistivities or concentrations. Wettling does not suggest the peak of conversion efficiency without substantial photo-degradation, which Applicants

discovered for the first time, for gallium-doped, quartz-crucible Czochralski silicon single crystals having a diameter of four inches or more and gallium concentrations or gallium-controlled resistivity in the claimed ranges. That is, Wettling does not suggest the peak of conversion efficiency without substantial photo-degradation for a solar cell could be produced by the claimed invention.

Wettling teaches that, in general, it is possible to prepare high conversion efficiency solar cells, having conversion efficiencies over 20%, but does not describe cell area or the prevention of cell degradation. Comparative Example 1 of the specification makes clear that, prior to the claimed invention, it was possible to produce solar cells having a conversion efficiency of 20%, if the area of the solar cell and the photo-degradation are ignored. See Specification, page 35, line 20 - page 36, line 16; Fraunhofer ISE PV Charts (attached). But that solar cell was of laboratory scale, 2 cm x 2 cm, and subject to photo-degradation. See Specification, page 32, Table 1. As discussed during the July 1 and December 16 interviews, a large area solar cell that is not subject to loss of conversion efficiency due to photo-degradation had not been produced and was considered a great challenge in the field of solar cell research. See Specification, page 2, lines 8-21; page 4, lines 2-4; Table 1 (the results of Comparative Example 4 disclose a 10 cm x 10 cm boron-doped Czochralski silicon single crystal having conversion efficiencies of 19.8 and 17.9 before and after photo-degradation, respectively). Wettling never discusses either cell area or the prevention of photo-degradation. Without a discussion of the cell area and other features of the solar cells, the conversion efficiencies disclosed in Wettling cannot be compared to the conversion efficiencies that can be achieved with the claimed invention.

As discussed in the Fraunhofer ISE PV Charts, cell area and efficiency are both important factors in evaluating a solar cell, since "[l]arge area solar cells tend to show lower efficiencies than small area cells of corresponding technology." Fraunhofer ISE PV Charts,

How to Read the ISE PV Charts. The largest area of any cell in the silicon single crystal cell chart having a conversion efficiency of ≥ 20% is 45 cm^2.

The claimed combination of producing the crystal according to the Czochralski method using a melt in contact with a quartz crucible, adding gallium as a dopant that controls resistivity of the crystal, using the gallium in an amount that produces a resistivity of 0.1 to 5 Ω·cm (claims 20, 22, 24, 27-42, 46 and 48), or a gallium concentration of 5×10^{17} atoms/cm^3 to 3×10^{15} atoms/cm^3 (claims 21, 44, 47 and 49), forming the single crystal with a diameter of four inches or more, and using the single crystal for a solar cell, makes the very high conversion efficiencies and minimal loss of conversion efficiency possible. See Specification, pages 29-35 (Examples); Table 1.

Thus, Wettling also fails to disclose several elements of the claimed combination.

4. All Three Cited References

None of the cited references teach or suggest the claimed combination. Indeed, all three references fail to disclose the selection of gallium rather than boron as the resistivity-controlling dopant in any amount that will produce a resistivity of 0.1 to 5 Ω·cm (claims 20, 22, 24, 27-42, 46 and 48), or a gallium concentration of 5×10^{17} atoms/cm^3 to 3×10^{15} atoms/cm^3 (claims 21, 44, 47 and 49), or forming a solar-cell-grade single crystal with a diameter of four inches or more in a Czochralski process using a melt in contact with a quartz crucible. As further discussed in detail below, all three of the cited references also fail to teach or suggest that a peak in conversion efficiencies without substantial photo-degradation could be obtained by way of the claimed invention in large-diameter crystals.

C. Level of Ordinary Skill in the Art

In determining obviousness, the Examiner must consider the level of ordinary skill in the art. Graham v. John Deere, 383 U.S. 1, 17, 148 USPQ 459, 467 (1966). The level of skill

in the relevant art, silicon single crystal solar cells and their fabrication, is reflected in the specification, the references and in the declarations.

At the time the invention was made, it was known to those of ordinary skill in the art to perform the Czochralski method using quartz or silica crucibles to melt the raw materials from which silicon single crystals are grown. See Wolf, page 9, first paragraph. However, it was also known that silicon single crystals grown in this manner contain a large and/or somewhat unpredictable amount of oxygen. See Wolf, page 16, second paragraph. In boron-doped crystals containing large amounts of oxygen, defects due to boron-oxygen pairs are generated, and the conversion efficiency is degraded by light irradiation. See Specification, page 4, penultimate line-page 5, line 3; page 20, lines 3-15.

While those in the art had good skill levels, they also considered solar cell conversion efficiency to <u>decrease</u> with increased wafer size. See Specification, page 23, lines 3-12; Abe Declaration of Record, submitted June 4, 2003, paragraph 7; Kimerling Declaration, paragraphs 6 and 14; Fraunhofer ISE PV Charts, <u>How to Read the ISE PV Charts</u>. In fact, the Fraunhofer ISE PV Charts show a maximum conversion efficiency of 17.5 ± 0.4 for Czochralski silicon single crystal solar cells having an area of approximately 100 cm^2, and expressly teach that "[l]arge area solar cells tend to show lower efficiencies than small area cells of corresponding technology." See Fraunhofer ISE PV Charts, <u>How to Read the ISE PV Charts</u>; *silicon cells monocrystalline*.

The Fraunhofer Institut Solare Energiesysteme (Fraunhofer ISE) openly accepts solar cell technology samples and measurements and publishes the Fraunhofer ISE PV Charts. Certified data included in the Fraunhofer ISE PV Charts represents a survey of the state of the art in research and industrial laboratories. See Fraunhofer ISE PV Charts. For each silicon single crystal solar cell tested by Fraunhofer ISE, the chart lists the measured conversion efficiency at standard conditions with the accompanying measurement uncertainty, whether

the solar cell is a laboratory or production cell, the cell area, the manufacturer and remarks, along with some additional properties and data, such as the testing date. As discussed in the explanatory section on How to Read the ISE PV Charts, cell area and efficiency are both important factors in evaluating a solar cell.

Those of ordinary skill in the art were unaware of the peak in conversion efficiency that Applicants discovered could be achieved in combination with substantially no photo-degradation and large diameter by selecting the conditions recited in the present claims. See Abe Declaration of Record, submitted June 4, 2003, paragraph 8; Kimerling Declaration, paragraphs 7, 11, 14 and 15. They believed that the way to improve solar cell semiconductors was to adjust boron content or oxygen content, move away from the Czochralski process altogether, or use special surface treatments. See Specification, page 7, final line to page 8, line 16; Kimerling Declaration, paragraph 7; Minahan, page 311, col. 1, second full paragraph; page 312, col. 1, sixth full paragraph (the cold crucible and Floating Zone methods are less contaminating than the CZ method); Table 5 (crystals formed by the cold crucible and Floating Zone methods include less oxygen impurities than Czochralski crystals); Wettling.

It was known that Czochralski electronics-grade crystals could be formed with diameters of four inches or more (see Wolf, page 1, fourth full paragraph; page 6, first full paragraph; page 8, third full paragraph; Fig. 7), but not that solar-cell-grade silicon single crystals could be formed by the Czochralski method in a quartz crucible with such large diameters and still have improved efficiency and lack of photo-degradation. See Specification, pages 7-8; Fraunhofer ISE PV Charts (showing no single crystal silicon cells with diameters of four inches or more having a conversion efficiency higher than 17.5%); Kimerling Declaration, paragraphs 6, 8-14 and 20-22.

Similarly, it was known that gallium could be used as a dopant in solar-cell-grade silicon single crystals (see, for example, Minahan, Abstract), but not that it could be used with

large diameters or with improved conversion efficiency without substantial photo-degradation, and it was not known that Applicants' claimed resistivity range/amount of gallium would produce the surprising peak in conversion efficiency without substantial photo-degradation in the range of 5 Ω·cm to 0.1 Ω·cm demonstrated in specification Figure 4 and Table 1. See Abe Declaration of Record, submitted June 4, 2003, paragraph 8; Kimerling Declaration, paragraphs 6-15. Similarly, it was known that high conversion efficiencies could be achieved in small-diameter crystals and with complex and expensive technologies, but not in large-diameter, quartz-crucible Czochralski silicon single crystals with high crystal strength and low photo-degradation. See Specification, page 1, second paragraph and page 32, Table 1, Comparative Examples 1-3; Wettling; Fraunhofer ISE PV Charts, *silicon cells monocrystalline*; Kimerling Declaration, paragraphs 6-15.

It is against this background, the level of ordinary skill in the art and the references of record, that the references cited in the October 27 Office Action must be considered. See In re Ehrreich, 590 F.2d 902, 908-09 (C.C.P.A. 1979). The art of record, including Minahan, Wolf and Wettling, taken as a whole, does not teach or suggest the claimed combination or that the claimed combination could achieve the major increase in light conversion efficiency with low photo-degradation and large diameter, at low cost, which moves solar energy farther than ever before into the realm of commercially practical alternative energy sources.

D. Lack of Motivation or Suggestion in the Art to Carry Out the Claimed Invention, and Unexpected Results

As discussed below, while bits and pieces of the invention were present among disparate teachings of various references in the prior art, there was no suggestion in the art that all of the limitations of the present claims could or should be combined, that their combination would have even a reasonable likelihood of producing the important and unexpected results achieved by Applicants. To the contrary, the prior art taught away from

combination of the features of the claimed invention. Certainly, nothing in the prior art taught that the claimed combination could achieve the major, and stable, increase in light conversion efficiency in a four-inch or larger diameter crystal reflected in Table 1 and Figure 4 of the present specification, which moves solar energy farther than ever before into the realm of commercially practical alternative energy sources.

1. Minahan in view of Wolf

The combination of Minahan and Wolf is improper and does not disclose or suggest the claimed combination or its benefits. Missing from Minahan and Wolf is, at least, (1) any disclosure or suggestion of a solar-cell-grade, gallium-doped, quartz-crucible Czochralski silicon single crystal or wafer of four or more inches in diameter, (2) such a crystal, gallium-doped in the concentration and/or resistivity ranges claimed, or (3) any disclosure or suggestion of the high level and peak of conversion efficiency without substantial photo-degradation for gallium-doped, quartz-crucible Czochralski silicon single crystals, especially having a diameter of four inches or more, and gallium concentration or gallium-controlled resistivity in the claimed ranges.

a) Minahan and Wolf Teach Away from the Use of Czochralski Quartz-Crucible-Produced Silicon Single Crystals

Minahan notes that problems relating to high oxygen content arise from the Czochralski process. See Minahan, page 311, col. 1, second full paragraph. Wolf similarly notes that oxygen content affects the performance of the wafers. See Wolf, page 11, third paragraph; page 30, first full paragraph. According to Wolf, oxygen-related defects such as swirl and stacking faults, thermal donor generation and oxide precipitation can occur unless the oxygen concentration is as low as 2×10^{17} atoms/cm^3. See Wolf, page 16, third full paragraph.

In addition, it was well known in the art that oxygen content is related at least to the planar resistivity and light conversion efficiency of silicon single crystal wafers, as discussed during the July 1, 2003 interview. See Specification, page 4, penultimate line to page 5, line 21; page 7, last line to page 8, line 16; page 23, lines 3-12; Abe Declaration of Record, submitted June 4, 2003, paragraph 7; Kimerling Declaration, paragraphs 6, 17, 20 and 21. As was also discussed in the interview, it was known in the art that the problems caused by oxygen content, such as photo-degradation associated with boron-oxygen pairings, increase with larger Czochralski crystal/wafer sizes. See Specification, page 4, penultimate line to page 5, line 21; page 7, last line to page 8, line 16; page 23, lines 3-12; Abe Declaration of Record, submitted June 4, 2003, paragraph 7; Kimerling Declaration, paragraphs 6, 17, 20 and 21. Contrary to the Office Action's assertion, it would not have been obvious to one of ordinary skill in the art to combine these references to produce a gallium-doped, quartz-crucible Czochralski silicon single crystal having a diameter of four inches or more and the recited gallium concentration and/or resistivity, at least because one of ordinary skill in the art would have expected crystals having larger diameters to have larger interstitial-oxygen concentrations and increased related problems. See Specification, page 4, penultimate line to page 5, line 21; page 7, last line to page 8, line 16; page 23, lines 3-12; Fraunhofer ISE PV Charts and associated discussion; Abe Declaration of Record, submitted June 4, 2003, paragraph 7; Kimerling Declaration, paragraphs 6, 17, 20 and 21. The claimed invention overcomes the problems of high oxygen content and large crystal size in quartz-crucible Czochralski crystals in a way not suggested by Minahan, Wolf or their combination, by using a gallium dopant to control resistivity, in the claimed concentration and/or resistivity ranges, and actually produces benefits from the resulting oxygen content. Kimerling Declaration, paragraph 13.

Minahan and Wolf teach directly away from the claimed invention, teaching away from the use of the quartz-crucible Czochralski process to achieve the present invention. Minahan suggests that other processes that are not desirable for forming large crystals, such as cold crucible or Floating Zone methods, minimize the oxygen content of the silicon single crystals. See Minahan, page 311, col. 1, second full paragraph; page 312, col. 1, sixth full paragraph (the cold crucible and Floating Zone methods are less contaminating than the quartz-crucible Czochralski method); Table 5 (crystals formed by the cold crucible and Floating Zone methods include less oxygen impurities than quartz-crucible Czochralski crystals). Similarly, Wolf teaches that Floating Zone crystals have a higher purity and lower oxygen contamination than quartz-crucible Czochralski crystals. See Wolf, page 21, third paragraph. Minahan and Wolf thus would have led one of ordinary skill in the art <u>away</u> from the claimed use of a quartz-crucible Czochralski crystal to overcome problems arising from the high oxygen content that was associated in the art with large-diameter, quartz-crucible Czochralski crystals, in favor of a process that would not be desirable for forming large-diameter crystals.

Minahan teaches that lowering the oxygen concentration of a silicon single crystal improves the electron beam irradiation tolerance, a phenomenon unrelated to photo-degradation effects. See Minahan, p. 310, col. 1, second paragraph; Kimerling Declaration, paragraph 18. But silicon single crystals made by the Czochralski process with a melt in contact with a quartz crucible inherently contain high concentrations of oxygen. See Wolf, page 16, second paragraph. The combination of Minahan and Wolf thus teaches that, in order to improve the electron radiation tolerance of a silicon single crystal solar cell, the solar cell should be fabricated from a silicon single crystal made by either the Floating Zone or cold crucible methods, to lower the oxygen concentration. Minahan and Wolf teach that the quartz-crucible Czochralski process is not desirable for producing improved silicon single

crystals for solar cells because Minahan and Wolf teach that low oxygen concentration is desirable for improved electron beam radiation tolerance, but that Czochralski crystals have high, and less predictable, concentrations of oxygen from dissolution of the quartz crucible. Thus these references teach away from the claimed invention in which the quartz-crucible Czochralski method is used to produce large yet highly efficient solar cell crystals having a long lifetime.

In addition, Minahan does not address the deleterious effects of lowering the oxygen concentration of a silicon single crystal, such as the effect on crystal strength. See Specification, page 7, lines 15-23 ("oxygen concentration in the crystal can be as high as that in a general single crystal produced according to the CZ method, especially can be as high as 20 atoms/cm^3 or less ... the strength of the crystal is high since an adequate amount of oxygen is contained therein."); Kimerling Declaration, paragraph 13. Wolf acknowledges that "the oxygen impurity content of CZ wafers offer added strength and intrinsic gettering potential" (pages 21-22), but does not provide any suggestion that the difficulties with such oxygen impurities in solar cells can be ignored or overcome.

In contrast, the claimed invention uses the quartz-crucible Czochralski process to fabricate large-diameter silicon single crystals using gallium as the dopant to control resistivity. This process can accommodate use of a large amount of silicon melt, allowing large-diameter silicon single crystals to be easily grown. These crystals can have a high concentration of oxygen, resulting from the use of a quartz crucible to contain the melt, and so have high crystal strengths, but are not degraded by light and maintain their very high conversion efficiencies because gallium is used at the recited levels as the dopant to control resistivity. See Specification, page 7, lines 19-23; page 13, lines 7-12.

Thus, rather than suggesting the claimed invention, Minahan and Wolf teach away from it and constitute evidence of non-obviousness.

b) Minahan and Wolf Teach Away from the Claimed Diameter Range

The combination of limitations of the claimed invention, including the claimed diameter of four or more inches for a solar cell crystal, is not taught or suggested by Minahan and/or Wolf. It was known that gallium could be used as a dopant in solar cell crystals (See Minahan, Abstract), but not that it could be used to achieve large-diameter solar cell crystals with improved conversion efficiency and without substantial photo-degradation. See Kimerling Declaration, paragraph 14. As discussed above, increasing the diameter of quartz-crucible Czochralski silicon single crystals was expected to result in problems, such as low conversion efficiency due to oxygen content in the crystal. See Specification, page 4, penultimate line to page 5, line 21; page 7, last line to page 8, line 16; page 23, lines 3-12; Fraunhofer ISE PV Charts, How to Read the ISE PV Charts; Abe Declaration of Record, submitted June 4, 2003, paragraph 7; Kimerling Declaration, paragraphs 6, 8-14, 20 and 22.

As discussed above, processes such as the Floating Zone and cold crucible methods result in crystals having lower oxygen concentrations. See Minahan, page 311, col. 1, second full paragraph; page 312, col. 1, sixth full paragraph (the cold crucible and Floating Zone methods are less contaminating than the Czochralski method); Table 5 (crystals formed by the cold crucible and Floating Zone methods include less oxygen impurities than Czochralski crystals); Wolf, page 11, third paragraph; page 16, third full paragraph; page 30, first full paragraph. However, such processes produce silicon single crystals having a smaller diameter than can be produced by the quartz-crucible Czochralski method. Wolf teaches that the Floating Zone method is limited by stability issues to a maximum diameter of approximately 100 mm (10 cm or 3.9 inches). See Wolf, page 21, third paragraph. Minahan teaches silicon single crystals grown by the cold crucible method with diameters of less than one inch. See Minahan, page 311, col. 1, first full paragraph; fourth full paragraph. Wolf

addresses increasing the diameters of crystals as a handling issue for electronics-grade silicon single crystals, but does not address issues associated with increased diameters such as impurity incorporation. See Wolf, page 1; page 8, third full paragraph; Fig. 7. Wolf does not provide any suggestion that a solar-cell-grade silicon single crystal could or should be made with the disclosed diameters with any reasonable expectation of success.

One of ordinary skill in the art would not have expected, in light of the understanding in the art that oxygen-impurity-related problems and inefficiency increased with increased diameter, that a high-efficiency, large-diameter, solar-cell-grade, quartz-crucible Czochralski silicon single crystal should or could be produced, without any teaching to the contrary. See MPEP §2145, paragraph X. D. 3. ("'known disadvantages in old devices which would naturally discourage search for new inventions may be taken into account in determining obviousness.' United States v. Adams, 383 U.S. 39, 52, 148 USPQ 479, 484 (1966)"). Increasing the diameter of Czochralski silicon single crystal sizes was contrary to the accepted wisdom in the art at the time of the invention, which was that increasing the diameter decreases solar cell conversion efficiency. See Kimerling Declaration, paragraphs 6, 8-14 and 20-22; Abe Declaration of Record, submitted June 4, 2003, paragraph 7; Fraunhofer ISE PV Charts, How to Read the ISE PV Charts. The mere fact that Applicants attempted and succeeded at producing a solar-cell-grade, quartz-crucible Czochralski silicon single crystal having a large diameter, with the unexpected peak in conversion efficiency illustrated in Specification Table 1 and Figure 4 coupled with resistance to photo-degradation, is evidence of the non-obviousness of the invention. See MPEP §2145, paragraph X. D. 3. ("The totality of the prior art must be considered, and proceeding contrary to accepted wisdom is evidence of nonobviousness. *In re Hedges*, 783 F.2d 1038, 228 USPQ 685 (Fed. Cir. 1986").)

Wolf discloses that it was known that electronics-grade crystals could be formed with diameters of four inches or more (see Wolf, Fig. 7), but not that solar-cell-grade silicon single crystals could be formed with such large diameters yet have improved efficiency and lifetime. Minahan discloses a solar-cell-grade, gallium-doped Czochralski silicon single crystal (see Minahan, Abstract), but not a gallium-doped, quartz-crucible Czochralski silicon single crystal having the claimed gallium concentrations or the claimed resistivity ranges or the claimed diameter of four inches or more. Minahan teaches away from large-diameter, quartz-crucible Czochralski silicon single crystal wafers, such as those of the claimed invention, and toward silicon single crystals of a smaller diameter formed by a less contaminating process. See Minahan, Abstract; page 311, col. 1, first full paragraph; fourth full paragraph. These teachings must be considered. See MPEP §2141.02 ("Prior art must be considered in its entirety, including disclosures that teach away from the claims").

Wolf would not have motivated one of ordinary skill in the art to modify Minahan for use in solar cells in a manner directly contrary to Minahan's teachings. Minahan suggests selecting a process that is not desirable for producing large-diameter crystals (see Minahan, page 311, col. 1, second full paragraph; page 312, col. 1, sixth full paragraph (the cold crucible and Floating Zone methods are less contaminating than the Czochralski method); Table 5 (crystals formed by the cold crucible and Floating Zone methods include less oxygen impurities than Czochralski crystals)). The combination of Minahan and Wolf is thus improper, insofar as the references themselves teach away from using their combination to arrive at a solar-cell-grade, gallium-doped, quartz-crucible Czochralski silicon single crystal, having a diameter of at least four inches and the claimed gallium concentrations or the claimed resistivity ranges. See MPEP §2145, paragraph X. D. 2. ("It is improper to combine references where the references teach away from their combination. *In re Grasselli*, 713 F.2d

731, 743, 218 USPQ 769, 779 (Fed. Cir. 1983)"). Thus, again, the applied references not only do not make the claimed invention obvious; they are evidence of its non-obviousness.

c) **Minahan and Wolf Do Not Teach the Selection of the Claimed Ranges or the Resultant Peak in Conversion Efficiency Without Substantial Photo-Degradation**

The resistivity of Minahan's Czochralski crystals is disclosed to be 0.07 or 10 Ω·cm. Minahan suggests that 10 Ω·cm is sufficiently low for solar cell purposes and only provides Czochralski solar cell data for a crystal having a resistivity of 10 Ω·cm. See Minahan, Tables 3(a)-3(c) (showing similar data for 2 Ω·cm boron-doped Czochralski crystals and 10 Ω·cm gallium-doped Czochralski crystals). However, as discussed during the July 1 interview, resistivities of 10 Ω·cm or more may be tolerated in electronics-grade silicon, but resistivities of more than 5 Ω·cm are unnecessarily high for solar-cell-grade silicon single crystals, at least because at resistivities of more than 5 Ω·cm, the conversion efficiency of the crystal is affected, and is markedly less than found with crystals having resistivities in the claimed range. See Abe Declaration of Record, submitted June 4, 2003, paragraph 8; Specification, Figure 4. This is particularly evident in light of the peak in conversion efficiencies for gallium-controlled resistivity in the range of 0.1 to 5 Ω·cm (claims 20, 22, 24, 27-42, 46 and 48 (especially 0.2 to 5 Ω·cm in claims 44 and 45)), or gallium concentrations in the range of 5 x 10^{17} atoms/cm^3 to 3 x 10^{15} atoms/cm^3 (claims 21, 44, 47 and 49).

In particular, Figure 4 shows conversion efficiency values (a variable not even contemplated by Wolf) just inside and just outside the claimed resistivity range. Minahan's Czochralski crystal resistivity values, 0.07 and 10 Ω·cm, are respectively below the lower end and twice as high as the upper end of the claimed range. See Minahan, page 310, col. 2, second full paragraph; Table 2. Figure 4 includes data points showing a loss of as much as

two full percentage points of conversion efficiency by going outside the claimed range (a very important difference when the theoretical efficiency is just 28%, as discussed during the interviews). Indeed, Table 1 and Figure 4 illustrate the criticality of the claimed range in the claimed combination, by showing that, within the claimed range in the claimed combination, conversion efficiencies without substantial photo-degradation for quartz-crucible Czochralski silicon single crystals having a diameter of at least four inches never before achieved in the prior art can be obtained. See also Glunz et al., *Prog. Photovolt. Res. Appl.* 2000, Vol. 8, pp. 237-240, 238 (of record) ("To our knowledge, this is the first time that an efficiency of more than 20% was achieved for a cell of 100 cm^2 on Cz-silicon"); see MPEP §2144.05, paragraph III ("Applicant can rebut a *prima facie* case of obviousness based on overlapping ranges by showing the criticality of the claimed range."); MPEP §716.02(c) ("Evidence of unexpected and expected properties must be weighed."). The data shown in Table 1 and Figure 4 clearly establish that the differences in results are unexpected and significant. Minahan provides no suggestion of the critical resistivity range of claims 20, 22, 24, 27-42, 44-46 and 48 for quartz-crucible Czochralski crystals.

The Office Action suggests that one of ordinary skill in the art would have been motivated by Minahan and Wolf to add a specific impurity concentration to obtain the claimed resistivity. Office Action, pages 4-5. However, the specific gallium-induced resistivity range, and gallium concentration range, in the combination of the claimed invention was not "desired" prior to the instant application. The peak in conversion efficiencies without substantial photo-degradation, which renders the specific resistivity and gallium concentration ranges desirable, was an unexpected result of the claimed combination and previously unknown. See Glunz et al., *Prog. Photovolt. Res. Appl.* 2000, Vol. 8, pp. 237-240, 238; Fraunhofer ISE PV Charts; Kimerling Declaration, paragraphs 9-15; Abe Declaration of Record, submitted June 4, 2003, paragraphs 7-8.

Nothing in Wolf or Minahan suggests that solar-cell-grade, quartz-crucible Czochralski crystals could be formed with such large diameters and still have improved efficiency and lifetime.

2. Minahan in view of Wolf and Wettling

Minahan, Wolf and Wettling do not disclose or suggest the claimed combination. Missing from Minahan, Wolf and Wettling is, at least, (1) any disclosure or suggestion of a solar-cell-grade, gallium-doped, quartz-crucible Czochralski silicon single crystal or wafer of four or more inches in diameter, (2) such a crystal, gallium-doped in the concentration and/or resistivity ranges claimed, or (3) any disclosure or suggestion of the high level and peak of conversion efficiency without substantial photo-degradation for gallium-doped, quartz-crucible Czochralski silicon single crystals having a diameter of four inches or more and gallium concentrations or gallium resistivity in the claimed ranges.

The Office Action suggests that it would have been obvious to combine the "radiation tolerant Si material of Minahan with Wettling et al.'s structure to form high efficiency and high radiation tolerant solar cells." Office Action, page 8. Wettling teaches a textured, doped surface is necessary for high-efficiency solar cells (see Wettling, Abstract; col. 4, lines 11-31), while Minahan teaches solar cells formed from polished silicon single crystal wafers having electron beam tolerance (see Minahan, page 311, col. 1, fifth full paragraph) and Wolf teaches electronics-grade silicon single crystals (see Wolf, page 6, first full paragraph). One of ordinary skill in the art would not have been motivated to combine Wettling with Minahan and Wolf to produce a high-efficiency, gallium-doped, quartz-crucible Czochralski silicon single crystal solar cell having a diameter of at least four inches, at least because Wettling fails to suggest that even its structure could achieve high conversion efficiency in a cell of the claimed diameter. Thus, there was no motivation in Wettling, Minahan and Wolf to combine these references to provide the claimed invention.

See MPEP §2145, paragraph X. C. ("there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify or combine the reference teachings").

When Wettling's teachings regarding dopants are applied to a silicon substrate, Wettling, at most, suggests doping the surface, by a process such as diffusion doping, with a silicon p^+ type dopant, and then doping the surface with a silicon n^{++} type dopant and texturizing the surface. See Wettling, col. 4, lines 11-14; col. 6, lines 38-48. As stated above, Wettling does not distinguish among dopants of any particular type. In particular, no distinction is made between such silicon p^+ type dopants as boron and gallium. In contrast, Applicants have discovered that controlling the resistivity of a quartz-crucible Czochralski silicon single crystal with gallium yields improved results over controlling the resistivity with boron. See Specification, page 20, line 16 - page 21, line 26. Specifically, Applicants have found that by controlling the resistivity of the quartz-crucible Czochralski silicon single crystals with gallium rather than with boron, problems relating to oxygen content can be overcome, even with large diameter crystals. Id.

Further, no reference, including Wettling, or combination of references teaches or suggests that such conversion efficiency can be achieved in large diameter crystals with long lifetimes. For instance, it was understood in the art that increasing the area decreases the efficiency and lifetime of solar cells. See Specification, page 4, penultimate line to page 5, line 21; page 7, last line to page 8, line 16; page 23, lines 3-12; Fraunhofer ISE PV Charts, How to Read the ISE PV Charts; Kimerling Declaration, paragraphs 6, 8-14 and 20-22; Abe Declaration of Record, submitted June 4, 2003, paragraph 7. By producing the crystal according to the Czochralski method using a melt in contact with a quartz crucible, adding gallium as a dopant that controls resistivity of the crystal in an amount that produces a resistivity of 0.1 to 5 Ω·cm (claims 20, 22, 24, 27-42, 46 and 48), or a gallium concentration

of 5 x 10^{17} atoms/cm^3 to 3 x 10^{15} atoms/cm^3 (claims 21, 44, 47 and 49), forming the single crystal with a diameter of four inches or more, and using the single crystal for a solar cell, Applicants were able to increase the efficiency, the area (thus increasing the productivity and lowering the cost) and the lifetime of solar cells, even though the crystals from which the solar cells were fabricated may contain high or unpredictable concentrations of oxygen. See Abe Declaration of Record, submitted June 4, 2003, paragraphs 7 and 8; Specification, Table 1 and Figure 4. Nothing in the prior art suggests such a combination or that such a combination would produce the low cost and far superior product achieved by Applicants and acclaimed by those of skill in the art.

The claimed combination must be considered in light of the art of record. As set forth in In re Ehrreich, references cannot be considered in a vacuum, but must be considered in light of the other references of record. In re Ehrreich, 590 F.2d 902, 908-09 (C.C.P.A. 1979). Wettling teaches an entirely different way to achieve high conversion efficiency, and provides no suggestion to make the claimed combination, or that such a combination could achieve high conversion efficiency without substantial photo-degradation. Nothing in the prior art taught that the claimed combination could achieve the major increase in light conversion efficiency without substantial photo-degradation at high diameter reflected in Table 1 and Figure 4 of the present specification, which moves solar energy farther than ever before into the realm of commercially practical alternative energy sources. See MPEP §2141.02 ("A prior art reference must be considered in its entirety, i.e., as a whole, including portions that would lead away from the claimed invention."); In re Ehrreich, 590 F.2d 902, 908-09 (C.C.P.A. 1979).

No reference teaches or suggests what was accomplished for the first time with the claimed invention; that is, producing a solar-cell-grade silicon single crystal by the Czochralski method using a melt in contact with a quartz crucible (and thus with a high

oxygen content), having a large area (due to the large diameter of at least four inches), including gallium as the dopant to control resistivity, and capable of having a high conversion efficiency (e.g., over 20%) that can be maintained because photo-degradation problems are avoided. S. W. Glunz et al., 100 cm^2 Solar Cells on Czochralski Silicon with an Efficiency of 20·2%, *Prog. Photovolt. Res. Appl.* 2000, Vol. 8, pp. 237-240, 238 (of record) ("To our knowledge, this is the first time that an efficiency of more than 20% was achieved for a cell of 100 cm^2 on Cz-silicon"); see Abe Declaration submitted herewith, paragraphs 6-7, 9, 13, 16-18; Kimerling Declaration, paragraphs 11-22. In a paper presented at the 12th International Photovoltaic Science and Engineering Conference as recently as 2001, these results were recognized as the highest conversion efficiency so far obtained for large-diameter, silicon single crystal solar cells. See Kawamoto et al., p. 289.

The claimed invention was compared to boron-doped Czochralski crystals and Floating Zone crystals having little or no oxygen content, and found to be far superior to boron-doped Czochralski crystals and at least comparable to boron-doped Floating Zone silicon single crystals in light degradation and maintenance of conversion efficiency. S.W. Glunz et al. (including Dr. Wettling himself as a co-author), Comparison of Boron- and Gallium-doped p-Type Czochralski Silicon for Photovoltaic Application, *Prog. Photovolt. Res. Appl.* 1999, Vol. 7, pp. 463-469, 468; Table I (of record); see Abe Declaration submitted herewith, paragraphs 6-8. Table I sets forth a detailed comparison of gallium-doped Czochralski and boron-doped Czochralski, Magnetic Czochralski, and Floating Zone silicon single crystal solar cells, and among the features listed for the four cm^2 cells are the conversion efficiencies (η (%)) before and after illumination. Id. at Table I and page 464, penultimate line. As is clearly evident from Table I, even though the conversion efficiencies for these small cells were all at least 20% before light irradiation, the conversion efficiencies

for the boron-doped Czochralski silicon single crystal solar cells were drastically decreased by light irradiation to values below 20%. Id. at Table I.

As is clear from Comparative Example 1 in the specification, it was possible prior to the claimed invention to achieve conversion efficiencies of 20% in small area (2 cm x 2 cm) solar cells in the laboratory, but these cells were subject to photo-degradation. See Specification, page 35, line 20 - page 36, line 16; Table 1. However, as discussed during the interviews, a large-area solar cell that is not subject to loss of conversion efficiency due to photo-degradation had not been produced and was considered a great challenge in the field of solar cell research. See Specification, page 2, lines 8-21; page 4, lines 2-4; Table 1 (the results of Comparative Example 4 disclose a 10 cm x 10 cm boron-doped Czochralski silicon single crystal having conversion efficiencies of 19.8 and 17.9 before and after photo-degradation, respectively); Fraunhofer ISE PV Charts, How to Read the ISE PV Charts ("Large area solar cells tend to show lower conversion efficiencies than smaller area cells of corresponding technology"); Glunz et al., *Prog. Photovolt. Res. Appl.* 2000, Vol. 8, pp. 237-240, 238 (of record) ("To our knowledge, this is the first time that an efficiency of more than 20% was achieved for a cell of 100 cm^2 on Cz-silicon"). .

Further, no researcher or commercial manufacturer had produced such a large-area silicon single crystal solar cell having such a high conversion efficiency, as discussed in the interviews. Abe Declaration submitted herewith, paragraph 18; Glunz et al., *Prog. Photovolt. Res. Appl.* 2000, Vol. 8, pp. 237-240, 238 (of record) ("To our knowledge, this is the first time that an efficiency of more than 20% was achieved for a cell of 100 cm^2 on Cz-silicon"). As shown in the Fraunhofer ISE PV Charts, the maximum conversion efficiency that had been achieved for a 100 cm^2 silicon single crystal was 17.5%, which is much lower than the maintainable conversion efficiencies such as 20% or more that can be achieved by the claimed invention. See also Kimerling Declaration, paragraphs 11-13; Abe Declaration

submitted herewith, paragraphs 16-18; Glunz et al., *Prog. Photovolt. Res. Appl.* 2000, Vol. 8, pp. 237-240, 238 (of record) ("To our knowledge, this is the first time that an efficiency of more than 20% was achieved for a cell of 100 cm^2 on Cz-silicon").

The combination of features of the claimed invention was not known, taught or suggested in the art, including Minahan, Wolf and Wettling or any combination thereof. No reference, including Wettling, or combination of references teaches or suggests that using gallium as the dopant to control the resistivity of a quartz-crucible Czochralski silicon single crystal with the claimed concentration and/or resistivity is connected to the ability to achieve large-diameter solar cells with the peak in conversion efficiency without substantial photo-degradation that can be achieved by the claimed invention. The Office Action asserts that "Wettling et al. discloses generically doped Si solar cells with comparable conversion efficiencies and there is not evidence that such efficiencies would have been achieved with Ga as the dopant" (Office Action, page 9), but no reference suggests that such conversion efficiencies could be obtained by way of the claimed invention, especially in large-diameter crystals. See, e.g., Fraunhofer ISE Charts, *silicon cells monocrystalline*.

3. **Summary**

It is not proper to take the isolated teaching of large-diameter electronics-grade Czochralski silicon single crystals from Wolf and combine it with isolated teachings of specific small-diameter, gallium-doped, solar-cell-grade, electron beam tolerant Czochralski silicon single crystals in Minahan, and to still further combine these teachings with isolated teachings of surface-doped high-efficiency solar cell structures in Wettling. Whether or not bits and pieces of the invention may have been present among disparate teachings of various references, the various references contain no suggestion in the art that all of the limitations of the present claims could or should be combined, or that their combination would have even a reasonable likelihood of success in producing the important and unexpected results achieved

by Applicants. Isolated teachings of the individual references cannot be combined to support a rejection for obviousness; the patentability of the invention should be determined "in terms of what would have been obvious to one of ordinary skill in the art at the time the invention was made in view of the Sum of all the relevant teachings in the art, not in view of first one and then another of the isolated teachings in the art." In re Ehrreich, 590 F.2d 902, 909 (C.C.P.A. 1979). Such a combination ignores, in addition to what is ignored by the combination of Wolf and Minahan as discussed above, the structural differences between the solar cells of Wettling and Minahan and the advantages discovered by the Applicants of using the claimed combination of features.

E. Reasonable Expectation of Success and Unexpected Results

The prior art as a whole teaches away from the claimed invention, and merely discloses disconnected bits and pieces, with no motivation to combine them to achieve the products, processes and results achieved by Applicants. The prior art as a whole fails to raise the expectation that the claimed combination would provide the unexpected results of the claimed invention that make solar power more accessible.

The Office Action erroneously asserts that it "would have been obvious to one of ordinary skill in the art at the time of the present invention to combine the references because Wolf et al. discloses common sizes of Cz Si ingots and Minahan discloses solar cells made from wafers cut from Cz Si ingots." Office Action, page 4. Contrary to the assertions in the Office Action, one of ordinary skill in the art would not have been motivated to combine Minahan and Wolf to produce larger crystals having more surface area for solar cell formation with any reasonable expectation of success, much less an expectation of the superior results achieved by Applicants for at least the reason that increasing the size of the silicon single crystal was understood in the art to increase the problems associated with oxygen contamination. See Specification, page 4, penultimate line to page 5, line 21; page 7,

last line to page 8, line 16; page 23, lines 3-12; Fraunhofer ISE PV Charts, How to Read the ISE PV Charts ("Large area solar cells tend to show lower conversion efficiencies than smaller area cells of corresponding technology"); Abe Declaration of Record, submitted June 4, 2003, paragraph 7; Kimerling Declaration, paragraphs 6, 8-14 and 20-22. Minahan and Wolf themselves teach away from using their combination to arrive at a solar-cell-grade, gallium-doped, quartz-crucible Czochralski silicon single crystal, having a diameter of at least four inches and the claimed gallium concentrations or the claimed resistivity ranges. See MPEP §2145, paragraph X. D. 2. ("It is improper to combine references where the references teach away from their combination. *In re Grasselli*, 713 F.2d 731, 743, 218 USPQ 769, 779 (Fed. Cir. 1983)").

The motivation to increase the size of the Minahan quartz-crucible Czochralski wafers with any reasonable expectation of success does not exist in the prior art. The only motivation to make such combination with a reasonable expectation that it would be successful or have improved results exists in Applicants' own disclosure, which constitutes impermissible hindsight motivation. This is contrary to the well-established case law on the subject, which requires that prior art must be viewed prospectively and not retrospectively using the patent as a blueprint to reconstruct the invention by indiscriminately picking and choosing parts and bits from the prior art. See, for example, Grain Processing Corp. v. American Maize-Products Co., 840 F.2d 902, 907, 5 USPQ2d 1788, 1792 (Fed. Cir. 1988) ("Care must be taken to avoid hindsight reconstruction by using 'the patent in suit as a guide through the maze of prior art references, combining the right references in the right way so as to achieve the result of the claims in suit.'"). See also In re Fine, 837 F.2d 1071, 1075, 5 USPQ2d 1596, 1600 (Fed. Cir. 1988) ("One cannot use hindsight reconstruction to pick and choose among isolated disclosures in the prior art to deprecate the claimed invention."). This is because "[t]o imbue one of ordinary skill in the art with knowledge of the invention in suit,

when no prior art reference or references of record convey or suggest that knowledge, is to fall victim to the insidious effect of a hindsight syndrome wherein that which only the inventor taught is used against its teacher." W. L. Gore Associates Inc. v. Garlock, Inc., 721 F.2d 1540, 1553, 220 USPQ 303, 312-13 (Fed. Cir. 1983), *cert. denied*, 469 U.S. 851 (1984). Instead, the well-established rule of law is that each prior art reference must be evaluated as an entirety and all of the prior art must be evaluated "as a whole." See W.L. Gore, 721 F.2d at 1550, 220 USPQ at 311.

Contrary to the assertions in the Office Action, one of ordinary skill in the art would not have been motivated to combine Minahan, Wolf and Wettling to produce larger crystals having more surface area for solar cell formation of gallium-doped silicon with excellent conversion efficiencies and without substantial photo-degradation with any reasonable expectation of success without the teachings supplied in the instant specification.

F. Additional Secondary Considerations

The unexpected results of the claimed combination and their significance and unexpectedness are unambiguously demonstrated by the present specification (e.g., Table 1 and Figure 4), by the reactions of those skilled in the art, and by the award discussed in paragraph 6 of Dr. Abe's Declaration of record.

In the year 2000, Glunz et al. exclaimed that Applicants' invention "is the first time that an efficiency of more than 20% was achieved for a cell of 100 cm^2 Cz-silicon." See Glunz et al., *Prog. Photovolt. Res. Appl.* 2000,Vol. 8, pp. 237-240, 238; Abe Declaration submitted herewith, paragraphs 6-7. As recently as 2001, Applicants' invention is cited for the concept that "[f]or a large-area Si solar cell of 100 cm^2, a conversion efficiency or 20.2% has been achieved." Kawamoto, p. 289. In an international conference of the leading scientists in the world in the area of solar cell technology (Photovoltaic Science and Engineering) in 1999, the paper disclosing Applicants' invention received a special award for

excellence given to the best research paper presented at the conference. See Special Paper Award; Abe Declaration of Record, submitted June 4, 2003, paragraph 6; Kimerling Declaration, paragraphs 10, 12 and 22.

Such industry acclaim constitutes clear, objective and unambiguous evidence of the non-obviousness of the claimed invention to those of the highest skill in the art, much less to those of ordinary skill in the art, and must be considered. See MPEP §716.01(a) ("Objective evidence must be considered whenever present").

After 50 years of silicon semiconductor solar cell development, none of the references connect gallium to the ability to achieve highly efficient large-diameter solar cells, nor has the industry been able to achieve the results of Applicants' invention in other commercial products. See Kimerling Declaration, paragraph 22; Abe Declaration submitted herewith, paragraphs 10-18. No reference, or combination of references, teaches the peak in conversion efficiency that can be achieved by doping with gallium in the recited amounts or to the recited resistivities, or that such conversion efficiency without substantial photo-degradation can be achieved in large-diameter, quartz-crucible Czochralski crystals with long lifetimes.

The Office Action states that "the examiner notes the PVSEC-11 paper but cannot ignore the references since that conference is not ultimately responsible for United States patentability determinations in this matter." This assertion mischaracterizes Applicants' arguments and flatly ignores the requirement that evidence of secondary considerations must be considered in making determinations of obviousness. Furthermore, it does not specifically explain why this evidence is insufficient. See MPEP §716.01.

The unexpected improvements in solar cell efficiency, size and lifetime, detailed in this application and in the referenced PVSEC-11 paper, are very significant in making solar technology much more competitive with conventional power technology, as discussed in the July 1 Interview. The opinion of the leading scientists in the world in the area of solar cell

technology that the claimed combination is a considerable improvement over the previously existing technology was established in the paper award, and is clear objective evidence of non-obviousness. Such objective evidence must be considered. MPEP §716.01 ("Objective evidence must be considered whenever present").

Rather than "ignore the references," the Office is required to consider the references, and the state of the prior art as a whole, along with the objective evidence of secondary considerations provided by the Applicants. See MPEP §716.01 ("Objective evidence must be considered whenever present"); MPEP §2141.02 ("Prior art must be considered in its entirety, including disclosures that teach away from the claims"). Furthermore, the Examiner is obligated to consider obviousness to "one of ordinary skill in the art" (35 U.S.C. §103(a)), not to ignore the evidence of the real world responses of those skilled in the art. As discussed in detail above, the prior art as a whole teaches away from the claimed invention to those of ordinary skill in the art, and merely discloses disconnected bits and pieces, with no motivation to combine them. See MPEP §2143.01 ("Obviousness can only be established by combining or modifying the teachings of the prior art to produce the claimed invention where there is some teaching, suggestion or motivation to do so found either explicitly or implicitly in the references themselves or in the knowledge generally available to one of ordinary skill in the art"); In re Ehrreich, 590 F.2d 902, 908-09 (C.C.P.A. 1979). Even those of high skill in the art found the invention unobvious and praiseworthy; this real world evidence should not be discounted by the Examiner.

The prior art as a whole fails to suggest the claimed invention and fails to suggest the unexpected results of the claimed invention that make solar power more accessible as confirmed by those of skill in the art who granted the PVSEC-11 award.

For the first time, in the claimed invention, a low-cost solar cell having a diameter of at least four inches, capable of a conversion efficiency of 20% or more, without significant

lowering of the conversion efficiency by photo-degradation, was formed without a need for the complex Wettling approach, and for the first time, researchers in the art saw the concrete potential for commercially viable solar power. This they rewarded with their acclaim and with the PVSEC-11 paper award. The evidence of secondary consideration must be considered, and confirms the non-obviousness of the claimed invention.

Given the level of skill in the art, there was no motivation to pick and choose isolated teachings of prior art directed to different problems and solutions to construct the claimed combination with its unexpectedly superior results. See MPEP § 2141.02 ("prior art must be considered in its entirety, including disclosures that teach away from the claims.") To the contrary, when presented with Applicants' invention, rather than proclaiming it obvious, those of ordinary skill in the art presented Applicants with an international award for the excellence of their paper and have continued to cite it as a milestone in the ensuing years. See Abe Declaration of Record, submitted June 4, 2003, paragraph 6; Glunz et al., *Prog. Photovolt. Res. Appl.* 2000, Vol. 8, pp. 237-240, 238 (of record) ("To our knowledge, this is the first time that an efficiency of more than 20% was achieved for a cell of 100 cm^2 on Cz-silicon"); Kawamoto et al., p. 289; Kimerling Declaration, paragraphs 10, 12 and 22. Thus, the evidence of the reaction of those of ordinary skill in the art further confirms the non-obviousness of the claimed invention.

There is no suggestion or motivation in Minahan, Wolf or Wettling to combine them or to modify them to produce the claimed combination and to thereby achieve the unexpectedly improved results of the claimed invention that make solar cell technology so much more commercially feasible. It was not known that Applicants' claimed resistivity range/amount of gallium would produce the surprising peak in conversion efficiency without substantial photo-degradation demonstrated in specification Table 1 and Figure 4. Contrary to the assertion in the Office Action, one of ordinary skill in the art would not have been

motivated to modify Minahan to provide quartz-crucible Czochralski silicon single crystal wafers having a gallium concentration in the range of from 5×10^{17} atoms/cm^3 to 3×10^{15} atoms/cm^3, or a resistivity in the range of 5 Ω·cm to 0.1 Ω·cm based on Figure 22 of Wolf, at least because the benefits of the claimed combination were previously unknown and not suggested by either Minahan or Wolf. Neither Minahan nor Wolf nor Wettling suggests that the benefits of the claimed invention arising from selection of a resistivity within the claimed critical range when gallium is the resistivity-controlling dopant, especially in a crystal having a diameter of at least four inches, as unexpectedly established by Applicants and demonstrated in specification Table 1 and Figure 4.

Thus the evidence of secondary considerations that must be considered in this case also confirms the non-obviousness of the claimed invention.

G. Conclusion

Considered in light of all of the factors relevant to an obviousness determination, Minahan, Wolf and/or Wettling, alone and together, do not teach or suggest the claimed combination or the unexpected results achieved thereby. Accordingly, reconsideration and withdrawal of the rejections are respectfully requested.

IV. Conclusion

In view of the foregoing, it is respectfully submitted that this application is in condition for allowance. Favorable reconsideration and prompt allowance of claims 20-22, 24 and 27-60 are earnestly solicited.

Should the Examiner believe that anything further would be desirable in order to place this application in even better condition for allowance, the Examiner is invited to contact the undersigned at the telephone number set forth below.

Respectfully submitted,

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Attachments:

Declaration Under 37 C.F.R. §1.132 of Dr. Abe

Declaration Under 37 C.F.R. §1.132 of Professor Kimerling

A. Wang et al., 24% Efficient Solar Cells, Appl. Phys. Lett. **57** (6) 602 (1990)

The Fraunhofer ISE PV Charts: Assessment of PV Device Performance, 11^{th} Edition, Update 1, June 26, 1998.

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